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THE CLOSED ON-SITE FUEL CYCLE OF THE BREST REACTORS

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ABSTRACT

The BREST fast reactor with nitride fuel and lead coolant is being developed as a reactor of new generation, which has to meet a set of requirements placed upon innovative reactors, namely efficient use of fuel resources, nuclear, radiation and environmental safety, proliferation resistance, radwaste treatment and economic efficiency. Mixed uranium-plutonium mononitride fuel composition allows supporting in BREST reactor CBR≈1. It is not required to separate plutonium to produce "fresh" fuel. Coarse recovered fuel purification of fission products is allowed (residual content of FPs may be in the range of 10^{-2} - 10^{-3} of their content in the irradiated fuel). High activity of the regenerated fuel caused by minor actinides is a radiation barrier against fuel thefts. The fuel cycle of the BREST-type reactors "burns" uranium-238, which must be added to the fuel during reprocessing. Plutonium is not extracted during reprocessing being a part of fuel composition, thus exhibiting an important nonproliferation feature.

The radiation equivalence between natural uranium consumed by the BREST NPP closed system and long-lived high-level radwaste is provided by actinides (U, Pu, Am) transmutation in the fuel and long-lived products (I, Tc) transmutation in the blanket. The high-level waste must be stored for approximately 200 years to reduce its activity by the factor of about 1000.

The design of the building and the entire set of the fuel cycle equipment has been completed for the demonstration BREST-OD-300 reactor, which includes all main features of the BREST-type reactor on-site closed fuel cycle.

KEYWORDS

Fast reactor; Closed fuel cycle; Non-proliferation; RW equivalence

1. INTRODUCTION

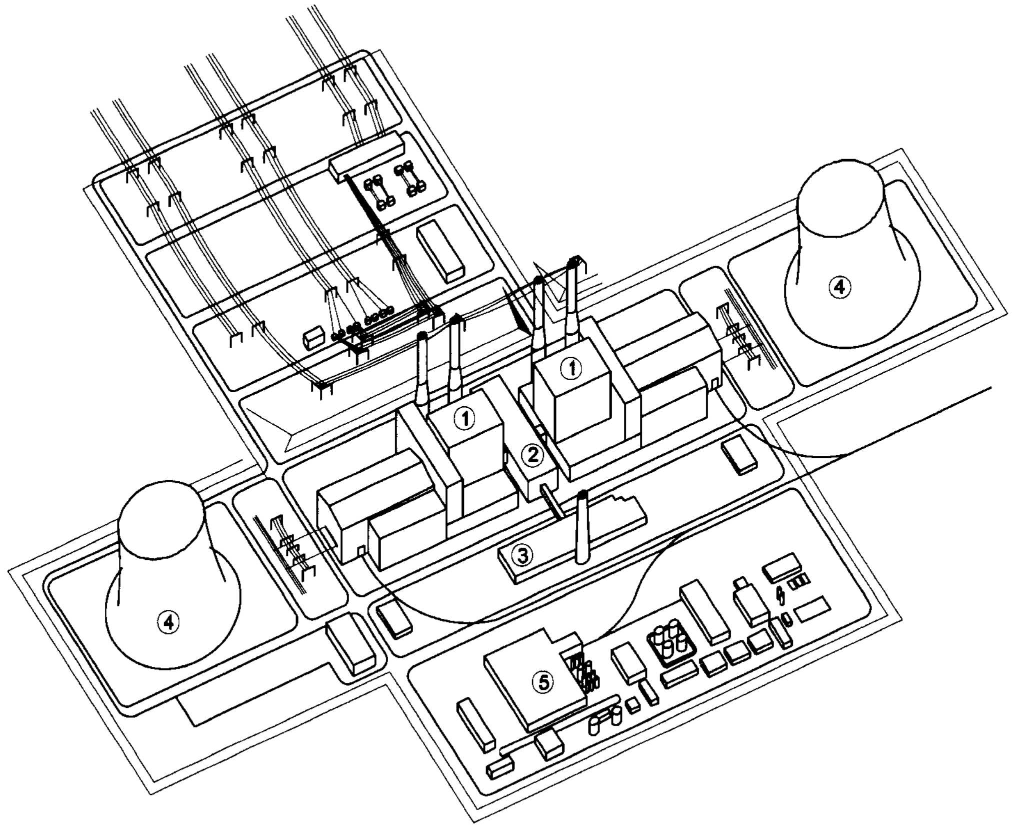
We cannot disregard current stagnation of nuclear power, but its causes are transient and not fundamental. Meanwhile, there appears to be no realistic alternative to develop nuclear for large-scale replacement of traditional fuels, and first of all hydrocarbons, to cope with the problem of progressive depletion of cheap fuel resources and pollution of environment with combustion products.

RF Minatom institutes during the last 10-15 years developed a fast reactor with high-density fuel (UN – PuN) of equilibrium composition and lead coolant (BREST) with on-site closed fuel cycle. Its main target was to meet the requirements to innovative nuclear power technology without going too far from the existing technologies developed for civic and military purposes.

2. THE FAST REACTOR BREST WITH ON-SITE FUEL CYCLE

The fast reactor BREST with nitride fuel and lead coolant is being developed as a reactor of new generation, which has to meet a set of requirements placed upon innovative reactors, namely efficient use of fuel resources, nuclear, radiation and environmental safety, proliferation resistance, radwaste treatment and economic efficiency. This paper discusses the BREST reactor concept from the viewpoint of its ability to meet the requirements for nonproliferation of nuclear materials and to establish a balance between the generated radioactive waste and the mined natural uranium.

The BREST-OD-300 NPP design includes the plant proper with a demonstration liquid-metal reactor BREST 300 MWe in capacity, the on-site closed fuel cycle and the complex for radwaste treatment and storage. The design studies have confirmed the feasibility of BREST reactors of various capacity (e.g. 600 and 1200 MWe) for the large-scale power industry of the future, following the same principles as those designed into the 300 MW reactor. The BREST-OD-300 facility is a pilot, demonstration power unit meant to validate and further develop the design features adopted both for the reactor facility and for the on-site fuel cycle with a radwaste management system. On completion of the essential studies, the power unit is to go into commercial operation in the grid. Subsequent commercialisation is expected to proceed with the NPP comprised of two BREST-1200 units and having an on-site fuel cycle, which has gone as far in its development as a full-fledged conceptual design (**Fig. 1**).



1. BREST-1200 reactor building. 2. Building of the on-site closed fuel cycle.
3. Radwaste treatment and storage building. 4. Cooling tower.
5. Auxiliary buildings

Fig. 1. General layout of the BREST NPP.

According to current expectations, the BREST-1200 plant design will rely on the BREST-OD-300 developments tried out in operation: fuel rods and assemblies, basic equipment of the plant proper and its on-site cycle. Transfer to the higher installed capacity will be achieved largely by increasing the number of the tried-out components. Thus, the transition from the pilot plant to a commercial facility may be effected with minimised time and money spent on it. It should be also mentioned that the on-site fuel cycle will be shared by the two power units.

The BREST-OD-300 fuel cycle promises virtually unlimited expansion of the fuel resources available to the nuclear power industry due to recycling of U-Pu fuel of equilibrium composition (CBR $\approx$ 1) which will require addition of but small quantities of depleted or natural uranium (Adamov et al., 2001). The fuel cycle arrangement allows attaining the radiation equivalence of nuclear materials with allowance made for their migration. To this end, the radioactivity and the nuclide composition of the waste subject to burial should be such that the heat and the stability of the buried materials and the degree of migration risk of the nuclides, with regard to their respective biological hazards, should be at least no worse than those found at natural uranium deposits (Lopatkin et al., 2002).

The on-site closed fuel cycle of BREST-OD-300 is designed for a capacity of 17.6 t (U,Pu)N/year under conditions of the first core fabrication and for ~ 3.5 t (U,Pu)N/year under conditions when the fuel is regenerated and refabricated. The fuel cycle is divided into the following sections:

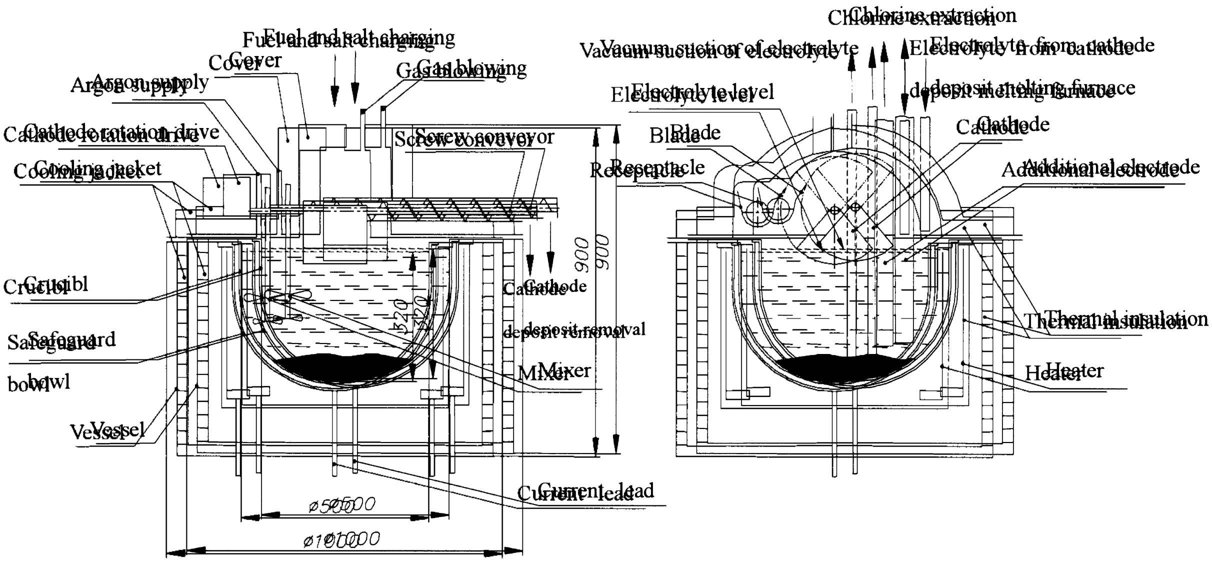
- production of plutonium mononitride;
- cutting of fuel assemblies and opening of fuel rods;
- regeneration;
- preparation of moulding powder and fuel fabrication;
- preparation of claddings and other fuel rod components;
- fabrication of fuel rods;
- manufacture of fuel assemblies.

The BREST-OD-300 fuel cycle design involves electrochemical reprocessing of irradiated nitride fuel with separation of uranium and plutonium in molten LiCI-KCI. The basic features of such a technology were developed at the Argonne National Laboratory (USA) and were elaborated in a whole number of efforts, including those undertaken by NRIIM. The fuel cycle equipment was designed by a special organisation of SverdNIIkhimmash. An example of such developments is the electrolyser for regeneration of mixed (U,Pu)N fuel (**Fig. 2**).

The on-site fuel cycle technology involves the following main processes:

- separation of FA heads and tails;
- separation of cladding and lead bond from fuel by dissolving the active part of fuel assembly in molten metallic zinc;
- preparation of LiCI-KCI salts with minimum oxygen content and melt saturation with uranium and plutonium trichlorides;
- anodic dissolution of irradiated nitride fuel in molten salts;
- sedimentation at the solid cathode of metallic U, Pu, Np, Am and some Cm;
- periodic additional separation of U and Pu from molten salts under altered conditions of electrochemical process during electrolyte recovery;
- vacuum melting of mixed metallic U-Pu-Np-Am-Cm + 10% RE at 1000°C;
- granulation, hydrogenation and nitration of the metallic mixture, production of nitride powder, and distillation of electrolyte to be returned to the electrolyser;
- pellet moulding and sintering;
- fabrication of fuel rods and assemblies.

All the processes are provided with systems for cleaning the released gases from aerosols and volatile radioactive elements (tritium, iodine, krypton).



Specification

1. Crucible capacity, maximum	50 dm^3
2. Electrolyte mass (LiCl-KCl, 12%UCl_3, 2%$PuCl_3$)	75 kg
3. Loaded nitride mass, maximum	11 kg
4. Operating melt temperature, maximum	500-550°C
5. Working atmosphere	argon
6. Pressure in electrolyser, maximum	0.01 MPa
7. Heater power, maximum	20 kW
8. Heater voltage, maximum	25 V
9. Working voltage in electrolysis, maximum	2 V
10. Electrolysis current	390 A
11. Process duration	11 h

Fig. 2. Electrolyser for regeneration of irradiated mononitride fuel

A distinguishing feature of the fuel cycle arrangement is the unattended mode of its processes, i.e. complete remote control of the basic process, equipment adjustment, repair and maintenance.

2.1. BREST-OD-300 fuel cycle assessed for compliance with the requirements for non-proliferation of nuclear materials

The BREST-OD-300 design is notable for its focus on engineering rather than organisational provisions for proliferation resistance. This conclusion is suggested by the following design features:

- no uranium blanket is provided for in the BREST-OD-300 design. If a specially manufactured Pu-breeding fuel assembly is installed in the reactor, considerable negative reactivity will appear, which cannot be missed when the reactor is restarted after refueling;
- the fuel cycle of BREST reactors is arranged without transporting irradiated fuel to an external reprocessing facility. After one-year cooling in the in-pile storage, the irradiated fuel assemblies are passed on to the fuel cycle facility via a transport passageway connecting it with the reactor compartment. Thus, the design eliminates all the risks and costs related to fuel shipment for regeneration and obviates the need for the associated handling and transportation equipment;
- both before and after regeneration, the BREST reactor fuel is unfit for production of nuclear weapon. The essential feature required of the regeneration process is the inseparability of uranium and plutonium with retention of their proportion in the regenerated fuel;
- fuel regeneration and refabrication take place in shielded chambers inaccessible to personnel;
- regenerated fuel contains up to 1% of fission products, which facilitates control over attempts to steal the nuclear material (this feature of the BREST reactor fuel is sometimes referred to as its "self-protection").

2.2. BREST-OD-300 radwaste management

Management of liquid and solid radioactive wastes of the BREST-OD-300 plant is arranged in compliance with the requirements of radiation-equivalent disposal.

The generated waste may be conventionally divided into two major categories:

- low- and medium-level liquid and solid wastes which are largely typical of NPPs. They emerge in a broad spectrum and relatively large volumes;
- high-level solid waste produced in the fuel cycle during regeneration of irradiated fuel and preparation of mixed uranium-plutonium fuel. This waste is distinguished by small quantities, very high specific activity, intensive heat release and high content of long-lived nuclides.

Waste management for the first category follows largely the traditional procedure (filtering, biofiltering, evaporation, sorption, concentrate solidification for liquid radwaste; sorting, pressing, burning for treated solid radwaste; compacting or long-term storage for untreated solid radwaste).

For the second category, waste management has no precedent either at Russian NPPs or at any foreign facilities.

Opening of fuel rods and regeneration of irradiated nitride fuel give rise to high-level waste of the following categories:

- noble elements (ruthenium, rhodium, palladium, etc.) as well as molybdenum, zirconium, technetium present as particles in molten salts (electrolyte). Their total quantity makes 0.32 t per year. Separation is carried out with the use of a porous metal filter which is reconditioned by molten lead. When these fission products build up to 10% by mass, they are removed into a container which after cooling, sealing and decontamination is sent on for long-term storage. Technetium is fractionated, with previous oxidation and distillation of the generated oxide Tc_2O_7. Technetium oxide undergoes condensation and will be stored before going to the reactor for transmutation;

- chlorides of rare-earth, alkali-earth and some other elements, mixed with electrolyte in the proportion of 1:1. Their total quantity is estimated at 1.8 t per year. Electrolyte regeneration involves previous extraction of uranium and plutonium, followed by separation of fission products through zonal crystallisation. The cleaned electrolyte is reused. The fraction of rare-earth elements and curium is enclosed in a nickel matrix with a fill of 10% by mass.

The alkaline earth metals fraction is enclosed in a copper matrix with a fill of 10% by mass. Cesium chloride is placed in a calcium phosphate matrix with the same fill;

- fuel claddings and other structural components of fuel assemblies. Their total quantity is assessed at 3 t per year. The ingots together with spent crucibles are loaded into containers which, upon sealing and decontamination, are sent away for long-term storage. Consideration is being given to the possibility of recycling this metal in the on-site fuel cycle, after its treatment by induction melting;

- spent gas filters and gas absorbers. With their service life over, these components are to be loaded into containers and filled with matrix material (cement).

The radwaste management design provides for waste division into separate flows with regard to its activity, aggregative state and other characteristics, with subsequent treatment of each flow in the most efficient and safe way. The treatment results in transportable final products of minimised volume, which safely confine their radionuclides during transfer, storage and disposal.

The engineering design of the radwaste handling system in the on-site fuel cycle calls for further research and development work to validate the design solutions, especially those pertaining to regeneration, fractionation and treatment of high-level waste resulting from fuel regeneration and fabrication.

3. CONCLUSION

The BREST reactor closed on-site fuel cycle meets the requirements of nonproliferation resistance and radiation equivalent radwaste disposal. The technical project has been performed and is now under expertise and authorization procedures in accordance with nuclear regulation laws of Russian Federation. Nevertheless, a lot of research and development work must be done for more deliberate experimental verification of the technical decisions made in the project.

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